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(54) Title: POSITIONING DEVICE AND METHOD FOR RADIATION TREATMENT
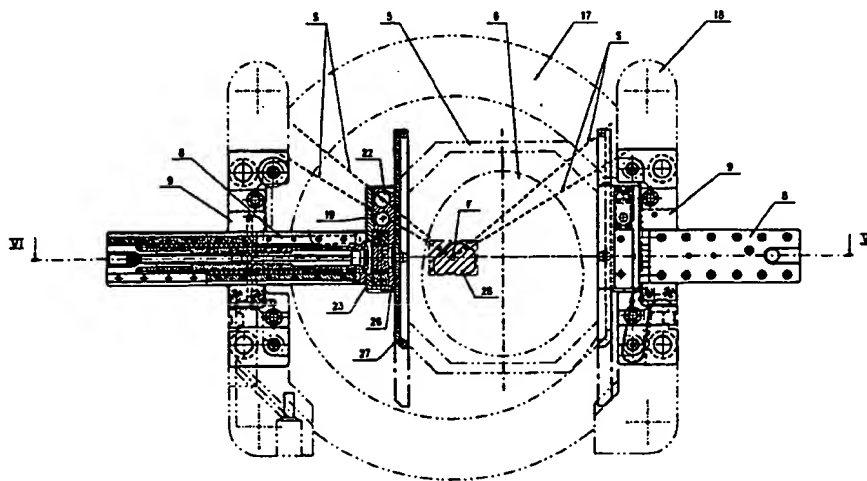
(57) Abstract

A radiotherapy appliance having controllable radiation beam(s) which converge on a focus volume wherein an object being irradiated can be movably positioned relative to the focus volume for varying time periods and with varying radiation exposure rates, optimally under control of a computer. The computer controls the focus volume radiation beam size, intensity and exposure time for subareas of the treatment target in response to a radiation dose distribution determined for the treatment target. A determination of the radiation beam size, intensity and dwell time of the focus volume in the target area, is made by initially dividing up the specified treatment area into volume elements or voxels and having biological characteristics of the treatment area assigned to each voxel. The energy deposition incident to each voxel to provide this biological characteristic is then calculated. Finally, from the energy deposition incident on each voxel, the dwell time of the focus volume at particular voxels can be determined. Once the dwell time has been determined, the computer generates a sequence of motor control movements to move the patient with respect to the focus volume such that the focus volume is at a position sufficiently long within the treatment target to deliver the necessary radiation for each voxel.

POSITIONING DEVICE AND METHOD FOR RADIATION TREATMENT

Field of the Invention:

This invention relates to a method and device for treating a patient with ionizing radiation. In the

5   practice of the invention, a patient is moved relative to an ionizing radiation source during treatment. By moving the patient during treatment, it is possible both to minimize radiation delivered to areas outside a target volume and to take into consideration, in treatment plan-

10   ning, the biological proterties of different areas inside and outside the target volume.

Background of the Invention:

It is known that exposure of tissue to ionizing radiation will kill the cells exposed. In the process of

15   conventional radiation therapy, however, significant volumes of normal tissue in addition to pathological tissue, are exposed to harmful levels of radiation.

Several methods have been employed in the prior art to minimize the exposure of healthy tissue to ionizing

20   radiation. For example, devices which direct radiation at the tumor from a number of directions have been used. In such devices, the amount of ionizing radiation emanating from each source of radiation is less than that which is necessary to destroy tissued. Rather, tissue destruction

25   occurs where the radiation beams from multiple sources converge, causing the radiation level to reach tissue-destructive levels. The point of convergence of the center of multiple radiation beams is referred to herein as the "focus point". The radiation field surrounding a focus

30   point is herein referred to as the "focus volume." The size of the focus volume can be varied by varying the size of the intersecting beams.

One such radiation appliance sold under the name GAMMA KNIFE (Elekta Instruments S.A.) comprises an

35   ionizing radiation shield having a substantial number of ionizing radiation sources. Radiation passes through a number of channels all of which lead toward a common focus

2

point in a recess within the radiation shield. Such a
system is referred to, and described in, US patent
4 780 898. Another system commonly termed a LINAC (or
linear acceleration) involves an ionizing radiation source
5   which moves circumeferentially around a focus point
delivering a series of beams of ionizing radiation through
the focus volume. A patient's head, immobilized in a
stereotactic instrument which defines the location of the
treatment target in the patient's head, is secured by a
10   system which positions the treatment target in coincidence
with the above-mentioned focus point.

The ionizing radiation in the focus volume of these
radiation appliances is intense compared to the radiation
emanating from each individual beam of the device. Areas
15   outside of the focus volume receive less substantial
amounts of ionizing radiation. Therefore, pathological
tissue can be treated while avoiding surrounding healthy
areas.

In general, the focus volume is spherical because the
20   intersection of multiple radiation beam cross sections
approximately form a sphere of constant radiation density
at each point equidistant from the focus point. As a
result, when the shape of the pathological tissue volume
is not substantially spherical, either some areas of
25   pathological tissue do not receive enough radiation or
other areas of healthy tissue receive too much radiation.
In other words, variations in radiation sensitivity within
the focus volume cannot be taken into acount. To ensure
that the whole volume of pathological tissue is fully
30   exposed to the radiation field, the radiation team is
obliged to deliver damaging doses of radiation to healthy
tissue within the focus volume.

It is possible to reduce the volume of healthy
tissue receiving high ionizing radiation doses by reducing
35   the size of the focus volume and manually repositioning
the patient a number of times such that the different
positions of the various focues volumes would effectively

3

cover the entire pathological tissue volume. While this
method allows increased conformity between pathological
tissue volumen and shape and the volume receiving high
radiation doses, the time required to manually reposition
5   a patient a sufficient number of times for the selected
focus volume size to effectively cover the pathological
tissue can require unreasonably long treatment periods.
Moreover, each manual reposition introduces the potential
for mistakes with resultant increased radiation of helthy
10   tissue.

A second potential means for minimizing the
irradiation of healthy tissue would be to vary individual
beam size and intensities whereby the shape of the focus
volume could be modified to conform more accurately with
15   the pathalogical tissue volume. With the many possible
combinations of incident beam sizes and intensities to be
interactively evaluated by the radiology team in order to
find a radiation dose distribution appropriate for
treating a pathological tissue volume having a specific
20   shape, the experience of the radiotherapy team in choosing
the beam sizes and intensities becomes a significant
factor in the efficiency and effectiveness of the
radiation treatment.

A further solution involves the projection of a focus
25   volume of ionizing radiation onto a treatment area. Such a
technique is described in, for example, Experimental
Verification of an Algorithm, for Inverse Radiation
Therapy Planning, Radiotherapy and Oncology, 17 (1990)
359-368. According to this article, it is impractical to
30   move the patient with respect to a fixed focus point. This
conclusion was based on Therapy Planning and Dosimetry for
the Pion Application at the Swiss Institute for Nuclear
Research, Radiation and Environmental Biophysics, 16,
205-209 (1979), which was reported to have demonstrated
35   that dynamic movement of the patient in a pion generaton
was not feasible.

4

Thus, although the prior art suggests radiation treatment of an object in which the dose distribution closely conforms to the treatment area within the object, the methods are dependent on the skill and experience of

5   the radiology team, involve potential errors during manual repositioning and/or require prolonged treatment times. In contrast to these prior art methods, the present invention - by means of automatic positioning and repositioning of a target area relative to a focus volume - eliminates the

10 risks of manual error, allows use of smaller focus volumes, thereby improving conformity between a radiation field and a target volume and reducing the need for trial and error approach associated with multiple size focus volumes, and shortens the treatment planning time. In

15 addition, contrary to the teaching of the prior art, the present invention permits dynamic movement of an object relative to a radiaton source, whereby greater local conformity of dose delivery to pathological tissue volume and shape becomes possible by movement at rates which

20 modulate radiation deposition based on the tissue cellular properties such as radiation sensitivity both inside and outside of the target volume.

Summary of the Invention:

The present invention provides a medical radiation

25 treatment method and apparatus having a focus volume, the position of which remains fixed with respect to the ionizing radiation source but is variable with respect to the object to be radiated. In the practice of the invention, an object is moved with respect to the focus

30 volume of an ionizing radiation source whereby a plurality of subareas within the object are subjected to varying radiation intensity levels for varying dwell times. The dynamic movement is guided by a computer controlled positioning device to provide a radiation dose

35 distribution. The radiation dose distribution closely conforms to a desired radiation dose distribution taking into account both the biological response of the various

tissues being subjected to radiation and the shape of the
target volume. The focus volume size and shape may be
varied in cooperation with the movement of the object to
further optimize the radiation treatment.

5   A determination of the focus volume size, intensity,
and dwell time of the focus volume in the target area, is
made by initially dividing up the specified treatment
volume into volume elements or voxels. Biological
characteristics of the treatment volume are then assigned

10   to each voxel. A probability for achieving complication
free control of pathological tissue is then calculated for
each voxel based on the biological characteristics. The
energy deposition incident to each voxel which is needed
to provide this probability of complication free tumor

15   control is thereupon calculated. Finally, from the energy
deposition incident on each voxel, the dwell time of the
focus volume at particular voxels is determined. Once the
dwell time has been determined, it is possible to
determine the order of movements necessary to position the

20   object with respect to the focus volume to deliver the
necessary radiation for each voxel.

       A device which allows a patient to be dynamically
positioned with respect to the focus point is used to
practice the method of this invention. In this device, a

25   computer is used to generate a number and order of motor
control movements which cause the target volume to be
moved and positioned with respect to the focus point for
the requisite time. In a preferred embodiment, a
positioning device is attached to a suspension arrangement

30   which is secured to a radiation appliance and is
translatable in the X, Y and Z directions via two
electronicallly controlled motor assemblies.

       Brief Description of the Drawings:

       Fig. 1 illustrates a radiation treatment system

35   according to the present invention.

6

Fig. 2 illustrates a flow chart for a computer program for use in a radiation treatment system according to the present invention.

Fig. 3 illustrates a modulator suitable for use in a
5 radiation treatment appliance according to the present invention.

Fig. 4 illustrates an alternate form of modulator suitable for use in a radiation treatment appliance according to the present invention.

10 Fig. 5 illustrates a suspension system for moving a positioning device with respect to a radiation source according to the present invention.

Fig. 6 depicts the embodiment of Fig. 5 along section VI-VI.

15 Detailed Description of the Invention:

Fig. 1 illustrates a radiation treatment system useful for carrying out the radiation treatment method according to the present invention. In particular, Fig. 1 illustrates the coordination of various parts of a
20 radiation treatment appliance 103, having an electronically controlled positioning device 105 and an ionizing radiation unit 110, to deliver controlled radiation to selected parts of an object under treatment. The use of an electronically controlled positioning device
25 in combination with calculated radiation doses for individual voxels based on biological radiation response characteristics enables the radiation system illustrated in Fig. 1 to dynamically control the radiation treatment of the target by moving the target with respect to the
30 focus point. Specifically, the radiation treatment system of Fig. 1 optimizes the radiation delivery of individual voxels on a real time basis so that radiation absorbed in the target conforms to the desired radiation doses associated with desired biological responses of the
35 various tissues to be treated.

7

Input data system 150, illustrated in Fig. 1,
comprises a system for generating and/or storing three
dimensional geometric coordinates of the treatment volume
within an object such as a patient. This system also
5   generates and/or stores the types of biological responses
of the target volume and surrounding tissues to be
treated. The input data system 150 transmits the treatment
volume data to the host computer system 100. The input
data system 150 is, for example, a conventional computer
10   graphics system which stores three dimensional coordinates
of a treatment volume and associated subvolumes of the
treatment volume with data representing biological
properties of the subvolumes. The host computer 100
converts this data into a series of motor control,
15   radiation beam size, and radiation beam energy output
control signals through a computer program such as
illustrated in Fig. 2. The host computer sends radiation
control signals to the radiation modulators 45 of the
radiation unit 110 device over wire 130 to control the
20   size and/or intensity of the radiation beams emanating
from the radiation source to irradiate the treatment
volume.

     The radiation unit 110 includes an radiation source
which projects one, two or more beams of radiation and a
25   means to control radiation beam size, such as modulators
45. The radiation source of the radiation treatment
appliance may be any of variety of conventional ionizing
radiation sources which produce an effective focus volume
of radiation. A focus volume is typically formed by the
30   intersection of plurality (two to several hundred) of
radiation beams emanating from the radiation source. The
beam axes are directed at a fixed point with respect to
the radiation source. The focus volume is the summation
(over the volume of the intersecting radiation beams) of
35   radiation densities from each of the intersecting
radiation beams. An effective focus volume can also be
formed by directing the axis of a single radiation beam

8

through a fixed point from a plurality (typically 2 to 360) of different angles. Such a technique is commonly used in linear accelerator type radiation units.

The host computer 100 also sends the motor control
5   signals through wires 120 to each of a first, a second and a third motor assemblies, each having motors 21, 22 and 25, within the electronically controlled positioning device 105. The first and second motor assemblies cooperate so that motors 21, 22 and 25 in the first
10 assembly always move precisely the same distance as motors 21, 22 and 25 in the second assembly. The first and second motor assemblies are each connected to feedback system 170 which compares the translation distance of motors 21, 22 and 25 in the first motor assembly with the translation
15 distances of motors 21, 22 and 25 respectively of the second motor assembly. When a pair of cooperating motors 21, 22 or 25 do not have approximately (i.e.> 0.2 mm difference) the same translation distance, an error detection feedback system 170 generates a feedback error
20 signal to terminate all motor movement and radiation exposure which is sent through wire 180 to the host computer system 100. When the computer system has terminated motor movement and radiation exposure due to this feedback signal, the motors can then be recalibrated,
25 and treatment restarted. Feedback system 170 also monitors the radiation intensity by monitoring the beam sizes produced by the radiation modulators which form the focus volume. The beam size is controlled by the host computer 100 through radiation modulators 45 for each beam. When a
30 modulator forms a beam having a cross section larger or smaller than desired, then the error detection feedback system 170 transmits an error signal to the host computer which, in turn, generates control signals to the cooperating motors which move the patient away from the
35 focus volume of the radiation treatment appliance. Alternatively, when the error detection feedback system 170 senses that the radiation beam size is not correct,

9

then feedback system 170 transmits an error signal to the host computer 100 which then turns off the radiation source.

Manual controller 160 consists of a joystick
5   mechanism or the like which generates signals for manually controlling cooperating motors 21, 22 and 25. These signals are transmitted to both sets of cooperating motors 21, 22 and 25 over wire 120 through host computer system 100. Monitor 165 dispays an image corresponding to a focus
10   point and a treatment volume as the treatment volume is moved with respect to the focus point in response to the signals sent to cooperating motors 21, 22 and 25.

Fig. 2 illustrates a computer program 200 used by a computer 100 of the radiation treatment system according
15   to the present invention for controlling radiation deposition within the treatment volume of an object by automatically moving the object with respect to the focus volume. The computer program generates signals to control motors which move the object so as to have a radiation
20   focus volume dwell in a location for a sufficient time to deliver the appropriate radiation intensity for that location. Initially, the three dimensional coordinates of the treatment volume and the biological characteristics of the tissue in the treatment (and surrounding) volume are
25   generated and sent 203 to the computer system. The treatment volume is then segmented 205 into volume elements or voxels having a minimum volume smaller than the focus volume which is generated at the intersection of the radiation beams. Biological responses to radiation of
30   tissue associated with the treatment area are then assigned 220 to the voxels. The specification of tissue types allows the treating physician to treat, through computer controlled radiation, different types of tumorous regions which may react differently to specific radiation
35   doses.

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Once the tissue types for each voxel have been
established, the computer program 200 selects a desired
biological response 230 for each voxel which depends on a
radiation dose for that voxel. This selection generates a
5   desired radiation dose distribution $\Phi(r)$ for the treatment
volume. A specific example of such a biological response
is the maximum probability of complication free control of
pathological tissue (P+) chosen for each voxel. P+ is the
probability of achieving control for a specific type of
10   tissue for a specified radiation dose minus the
probability of fatal complications for that radiation dose
and tissue type. The data relating to the probability of
control is provided to the computer program from ongoing
or previously published clinical studies. Selecting a
15   maximum P+ for each voxel generates an optimum radiation
distribution for pathological tissue control because each
selected P+ has an associated radiation dose. The
generation of P+ can alternately be defined as the
probability of control for a specific type of tissue for a
20   specified radiation dose minus the probability of adverse
(not necessarily fatal) complications from that radiation
dose for that type of tissue. Alternatively, biological
responses of tissue to radiation may be selected depending
on the location of the treatment volume relative to other
25   treatment volumes. Further, other biological responses of
tissue to radiation may be chosen which would generate
different radiation dose distributions for the tissue.
These selections of biological response provide a treating
physician more degrees of freedom in treatment doses for
30   different types and locations of tissues.

Once a desired radiation dose $\Phi(r)$ for each voxel has
been generated in step 230, the computer program 200 must
specify how any particular voxel will receive the required
dose. This is a problem because radiation beams focused on
35   any one voxel will contribute radiation exposure to
adjacent voxels. The computer program 200 solves this
probelm by first determining 240 an energy deposition

kernel $H(r,r')$ which is the mean specific energy imparted to a point r per unit energy incident on a volume centered at r'. The program 200 assumes that $H(r,r')$ is spatially independent. That is, the energy imparted at point r from

5 a focus volume centered at r' is only a function of the distance between r and r'. A consequence of this assumption is that the calculated dose distribution $D(r)$ can be expressed as the integral of the density $F(r')$ of energy deposition kernels $H(r,r')$ over the same volume.

10 The integral expression is then solved via conventional analytical or iterative techniques for one of $D(r)$ or $F(r')$ given $H(r,r')$ and either $F(r')$ or $D(r)$ respectively. The energy depostion kernels $H(r,r')$ are known and are inputs for the integral expression because the energy

15 distribution associated with the physical intersection of multiple radiation beams of a given cross section for any one focus volume is known. The kernel may be simulated, for example, by rotating a normalized beam cross section through 360 degrees. Energy deposition kernels H are

20 assigned to each voxel in step 240.

Once the energy deposition kernels for all voxels have been determined, the calculatd radiation dose distribution $D(r)$ is determined by iteratively solving for the radiation density $F(r')$. That is, an initial density

25 $F_0(r')$ for each voxel is assumed, multiplied by the deposition kernel for each voxel, and then summed over the total treatment volume. The initial calculated dose distribution $D_0(r)$ is then compared 250 to the desired radiation dose $\Phi(r)$ and an error term is generated. The

30 assumed initial density is adjusted $F_1(r')$ as a function of the error term and the next $D_1(r)$ is calculated. This iteration procedure continues until the calculated $D_n(r)$ after n iterations is sufficiently close to the desired $\Phi(r)$. The initial assumed density is chosen to deliver a

35 substantial overdose to the treatment area. The error term represents a decrease in beam density. As a result, the convergence of the iterative calculations will guarantee

12

that the treatment area will not receive less than the
desired dose. This consideration assures that there will
not be an underexposure of a treatment area. The result of
iteration step 250 is a density F(r) for each voxel which
5 specifies the time duration that a specific kernel should
dwell on any one voxel. Typically, the iteration converges
at approximately n=200 or before.

Once the duration of a specific kernel on any
particular voxel is known, the computer 100 generates
10 (270) control signals which are sent to the modulators 45
and to both sets of cooperationg motors 21, 22 and 25. The
control signals sent to the modulators 45 adjust the
radiation beam size, and hence the kernel size for any
selected voxel. The control signals sent to the
15 cooperation motors, 21, 22 and 25 move the patient with
respect to the focus volume such that the radiation energy
incident on the focus volume has a duration on any
particular voxel only long enough to deliver the required
beam density to that particular voxel. The movement of the
20 target volume relative to the focus volume may be
continuous while the target volume is exposed to radiation
and the speed may be slowed or accelerated to result in an
appropriate dwell time. Alternatively, movement may
comprise sequential movement or re-positioning of the
25 target volume in a multiplicity of positions relative to
the focus volume. In this case, the radiation source is
pulsed off while the target volume is moved and pulsed on
while the target volume is stationary. As used herein, the
term "sequential movement" means that stopping the
30 movement of the target volume, irradiation the target,
volume, and moving the target volume again. In a preferred
embodiment, the focus point is not moved outside of the
object containing the target volume while this sequential
re-positioning is occurring.
35 Cooperating motors 21, 22 and 25 as well as
modulators 45 will continue to control the radiation
deposited in the patient until the feedback system 170 of

the radiation treatment system detects that either the
opposing motors are not moving synchronously or that one
or more of the radiation sources are not producing the
required beam intensity or that the modulators 45 are not
5   producing the required beam shape. When either of these
conditions occur, the computer program will generate 280
commands to stop motor movement and/or stop radiation
exposure. At this point, the program 200 will prompt the
user 285 for an evaluation of whether to proceed with the
10   remaining computer controlled treatment or proceed with
manual operation. When the user wants to return to
computer control, a new sequence of control movements are
generated 270 taking into account that part of the
previous treatment already accomplished. When the user
15   requests manual operation, the program releases control
over the radiation treatment system and transmits signals
from the manual controller 160 to both sets of cooperating
motors 21, 22 and 25.

The apparatus described above may be adapted to any
20   radiation unit 110 which delivers ionizing radiation to a
focus volume, such as a Gamma Knife^{TM} or LINAC radiation
treatment system, or a heavy particle beam system. In
order to control radiation delivery, the channel(s)
through which radiation is delivered may be provided with
25   radiation modulators 45 such as shown, in Fig. 3. The
radiation modulators 45 may be configured as opposingly
faced lead plates or wedges of the like which are moveable
relative to each other to form a variable slit of opening
for modulating the shape or intensity of the radiation
30   beam passing though the opening.

Fig. 3 illustrates a top view of modulator 45. In
particular, moveable lead plate 60 is disposed over
moveable lead plate 70. Plate 60 has a diamond shaped
opening 62 therethrough and plate 70 has a diamond shaped
35   opening 72 therethrough. Openings 62 and 72 converge to
form opening 65 through both plates 60 and 70. The
relative position of plates 60 and 70 determine the size

14

of opening 65 through which a radiation beam passes. The
size of opening 65 shapes the radiation beam passing
through opening 65.

    Fig. 4 illustrates an alternate form of modulator
5   suitable for incorporation in the present invention. The
modulator illustrated in Fig. 4 is formed from two sets 80
and 82 of opposingly oriented slats of radiation blocking
material. The slats may also be formed of radiation
modulating material which transmits selective intensities
10 of radiation depending on the energy of the incident
radiation. Individual slats within a first or second set
form a planar surface substantially perpendicular to the
direction of the radiation beam. The two sets of slats are
oriented with respect to each other such that they form
15 the radiation beam cross section. The slats are moveable
with respect to each other, and as they are moved, the
beam cross section is modulated. For example, slat 80(a)
moves relative to slat 82(a) to form part of opening 85
and slat 80(b) moves relative to slat 82(b) to form
20 another part of opening 85. Any other suitably shaped and
sized modulator may be used in the practice of the
invention.

    The radiation sources within the radiation unit 110
are preferably ionizing radiation sources which emit high
25 energy (gamma or x-ray) photons or heavy charged
particles.

    As illustrated in Fig. 5 and 6 an object such as a
patient's skull 6 is immobilized with respect to a
fixation device 5 within an electronically controlled
30 positioning device 105. The electronically controlled
positioning device 105 includes a base 17, a suspension
system, and a fixation device 5. The fixation device 5 is
moveable with respect to the radiation device. During
treatment, the fram 5 is moved by the positioning device
35 to the positions necessary to allow the focus point F of
the radiation beams to be located within the target volume
28. The focus point is at the intersection of the

15

plurality of radiation beams S. The positioning device is
secured to the radiation appliance by a base 17. The
suspension system, attached to the base 17 by bracket 18,
translates the fixation device 5 in the horizontal and
5   vertical planes, i.e. the 3 dimensional coordinate system,
with respect to the radiation source and the focus point
F. This suspension arrangment comprises a pair of
horizontal beams 8 or the like which are oriented in line
with each other, translatable in their lengthwise
10   direction, and slidably supported in associated guides 9
of bracket 18.

        The outer end of each beam 8 is connected to the
associated part of the bracket through a screw jack means
19 which via gear assembly 20 is linked to an
15   electronically controlled motor 21 within the beam 8. The
motor 21 is in a parallel orientation to the screw
components of the screw jack means 19, as shown in Fig. 6.
The motor 21 is preferably operated via NC control from
the computer or the like (not illustrated) following a
20   dedicated computer program. Both motors 21 function
cooperatively and form a motor assembly arranged to
translate the stereotactic instrument 5 in the X
direction.

        Additionally, adjacent the inner end of each beam 8,
25   an electronically controlled motor 22 is connected to, and
supported by, a beam 23 which encloses a screw jack means
24 also connected to the motor 22. The beams 23 are
parallel and disposed opposite each other. The motors 22
are also electronically controlled, operated via NC
30   control from the computer and cooperate to form a motor
assembly arranged to translate the stereotactic instrument
in the Z direction.

        A further electronic motor 25 is connected to, and
supported by, a beam 26 adjacent the inner end of each
35   beam 8, beyond the respective beam 23. The beams 26 are
mutually parallel and disposed opposite each other. Each
beam 26 is attached to the static portion of a respective

16

screw jack means 24 and guided with guides (not shown).
The screw jack means (not shown) are further connected to
the respective motor 25. The motors 25 are also
electronically controlled, operated via NC control from
5   said computer or the like and cooperative to form a motor
assembly which is arranged to translate the stereotacic
instrument 5 in the Y direction. The screw jack means (not
shown) supports an attachment means 27 to releasably
secure the stereotactic instrument in a defined position
10 in the suspension arrangement.

A fixation device 5 suitable for use in this
invention when immobilizing a patient's skull in the
positioning device is, for example, a stereotactic frame.
The frame is fixed to the skull of the patient and mounted
15 to the suspension system. The frame may be fixed to the
skull of the patient by means of surgical twist drills
passing through skin and looking into underlying bone.
Alterntively, the fixation device 5 may be one which is
non-invasive and/or allows the frame to be relocatably
20 positioned on the patient.

The pair of cooperating motors 21 are opposingly
disposed and operate in synchronization. In particular,
when the motors do not move the stereotactic frame
concurrently the same distance, then the error detection
25 feedback system 170 (not shown) connected to the pair of
cooperating motors 21 signals the computer that the
orientation of the stereotactic fram is not correct and
the program moving the sterotactic frame is stopped so
that the stereotactic frame can be reoriented.
30   A personalized computer program for a patient's
treatment controls the movements of each motor assembly
21,21; 22,22 and 25,25. In this way, the stereotactic
instrument 5 and therefore the patient's skull 6 is moved
in the X, Y and Z directions within the helmet 17 and
35 different parts of the treatment target 28 are
successively positioned at the focus point F for various
time periods in accordance with said program. The

17

movements of both of the motors in each motor assembly are
continuously checked against each other by the computer
and if the movement of one motor differs from the
respective cooperation motor, the computer issues a stop
5   signal and treatment is suspended. Computer operation
gives enhanced reliability and even the possibility, if so
desired, to break off treatment and to afterwards resume
treatment at the appropriate point in the computer
program.

10   While this invention has been particularly described
and illustrated with reference to particular embodiments
thereof, it will be understood by those of skill in the
art that changes in the above description or illustrations
may be made with respect to form or detail without
15   departing from the spirit or scope of the invention. In
particular, any controlled movement means which allows the
object being irradiated to be moved relative to a
radiation source may be employed.

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CLAIMS

1. A method of selectively irradiating an object, comprising determining the position of a focus point with respect to a radiation unit; immobilizing an object with
5   respect to a fixation device; coupling said fixation device to a suspension system; fixing a position of said fixation device by said suspension system with respect to said radiation unit to determine the position of said object; and moving said fixation device by said suspension
10 system with respect to said focus point to expose said object to radiation from said radiation unit.

2. A method of selectively irradiating an object, as in claim 1, further comprising exposing said object to radiation while moving said object.

15   3. The method of selectively irradiating an object, as in claim 1 or 2, further comprising modulating a radiation beam of said radiation unit to modulate a focus volume of said radiation unit.

4. The method of selectively irradiating an object,
20 as in claim 1 or 2, further comprising modulating a radiation source of said radiation unit to modulate a focus volume of said radiation unit.

5. A method of selectively irradiating an object, as in claim 1 or 2, wherein said object maintains a position
25 with respect to said focus point during said movement such that said focus point remains inside said object while said object is being moved.

6. The method of selectively irradiating an object, as in claim 1 or 2, further comprising subdividing a
30 treatment area of said object into a plurality of voxels; selecting a biological response to radiation for a plurality of said voxels; determining a radiation dose corresponding to each of said voxels to produce said biological response; and maintaining said object at a
35 location with respect to said focus point for a time sufficient to deposit said radiation dose corresponding to each of said voxels into each of said voxels.

19

7. A method of selectively irradiating an object, as
in claim 6, wherein said radiation dose corresponding to
each of said voxels is determined with respect to
radiation doses corresponding to adjacent voxels.

5   8. A method of selectively irradiating an object, as
in claim 2, wherein said object maintains a position with
respect to said focus point during said movement such that
said focus point remains inside said object while said
object is being moved.

10   9. A radiation appliance, comprising a radiation unit
for irradiating an object with a focus volume and a
fixation device coupled to said radiation unit by a
suspension system, wherein said fixation device
immobilizes an object to be irradiated by said radiation

15   unit, and said suspension system moves said fixation
device to expose and/or while exposing said object to
radiation.

10. A radiation appliance, as in claim 9, further
comprising a computer coupled to said suspension system

20   for controlling said suspension system said suspension
system responds to signals transmitted from said computer
by moving said fixation device to expose and/or while
exposing said object to radiation from said radiation
unit.

25   11. A radiation appliance, as in claim 10, wherein
said computer is coupled to said radiation unit and said
computer transmits signals to said radiation unit to
modulate at least one radiation beam emitted from said
radiation unit.

30   12. A radiation appliance, as in claim 10, wherein
said computer is coupled to said radiation unit and said
computer transmits signals to said radiation unit to
modulate a radiation source of said radiation unit.

13. A radiation appliance, as in claim 11, further
35   comprising an error detector coupled to said radiation
unit, said suspension system and said computer; said error
detector detects when said suspension system does not move

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said fixation device as indicated by said signals received
by said suspension system from said computer; said error
detector detects when said radiation unit beam is not
modulated as indicated by said signals sent from said
5   computer; and said error detector transmits an error
signal to said computer when said error detector detects
an error.

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AMENDED CLAIMS
[received by the International Bureau on 31 October 1995 (31.10.95);
original claims 1-13 replaced by amended claims 1-6 (2 pages)]

1.   A device to position a patient's skull (6) within a
radiosurgical appliance, such as the Gamma Knife™ which
comprises a radiation shield (2) having a substantial
number of radiation sources and corresponding channels
directed towards a common focus point (F) in a recess
within the radiation shield;
the positioning device comprising a helmet (17) having
channels extending therethrough corresponding in number
and orientation to the channels in the radiation shield, a
couch assembly (14) which is moveable along a stationary
base (13) secured adjacent the radiosurgical appliance, a
bracket device (18) on the couch assembly to firmly secure
the helmet thereby allowing it to be introduced into the
recess in the radiation shield, and a stereotactic
instrument (5) in which the patient's skull is immobilized
in order to locate a treatment target (28) in the skull,
wherein the stereotactic instrument (5) is adapted to be
secured relative to the helmet so that the target can be
brought into coincidence with said focus point;
characterized in that the stereotactic instrument (5) is
clamped in a suspension arrangement (8, 19-27) which is
secured to the bracket device (18) and is translatable in
the X, Y and Z directions via three electronically
controlled motor assemblies (21,21; 22,22; 25,25) operated
by a computer or the like, such that different parts of
the treatment target (28) can be successively or
continuously positioned in the focus point (F) for
individual time periods and with individual rates, under
control of said computer.

2.   A device according to claim 1, characterized in that
each motor assembly (21,21; 22,22; 25,25) comprises a
pair of cooperating motors whereby the first motor
(21,22,25) in each assembly is disposed on a first side of
the stereotactic instrument (5) and the second motor

(21,22,25) is disposed on the opposite side of the
stereotactic instrument (5).

3.   A device according to claim 2, characterized in that
5   the motors (21,21; 22,22; 25,25) are controlled via NC
control whereby the movements of the motors in each motor
assembly are checked against each other and a stop signal
is issued by said computer if the movement of one motor
differs from that of the respective cooperating motor.
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4.   A device according to any preceding claim,
characterized in that the suspension arrangement (8,19-27)
is connected to the bracket device (18) via a pair of
horizontal, or alternatively vertical, beams (8) which are
15   in line with each other and translatable in their
longitudinal direction, the respective outer ends (15) of
which are propelled by respective motors (21,22,25) in the
associated motor assembly (21,21; 22,22; 25,25) and the
respective inner ends of which support a motor associated
20   with one of the other motor assemblies.

5.   A device according to claim 4, characterized in that
the outer end (15) of each beam (8) is connected to the
associated portion of the bracket device (18) via a motor
25   driven screw jack means (19), and in that each beam (8) is
slidably supported in a respective guide (9) in the
bracket device (18).

6.   A device according to claim 4 or 5, characterized in
30   that the motors (21,21) belonging to the beams (8) are
arranged to be driveable in opposite directions in order
to propel the beams toward or away from each other so as
to respectively release or secure the stereotactic
instrument (5) in the suspension arrangement (8, 19-27).
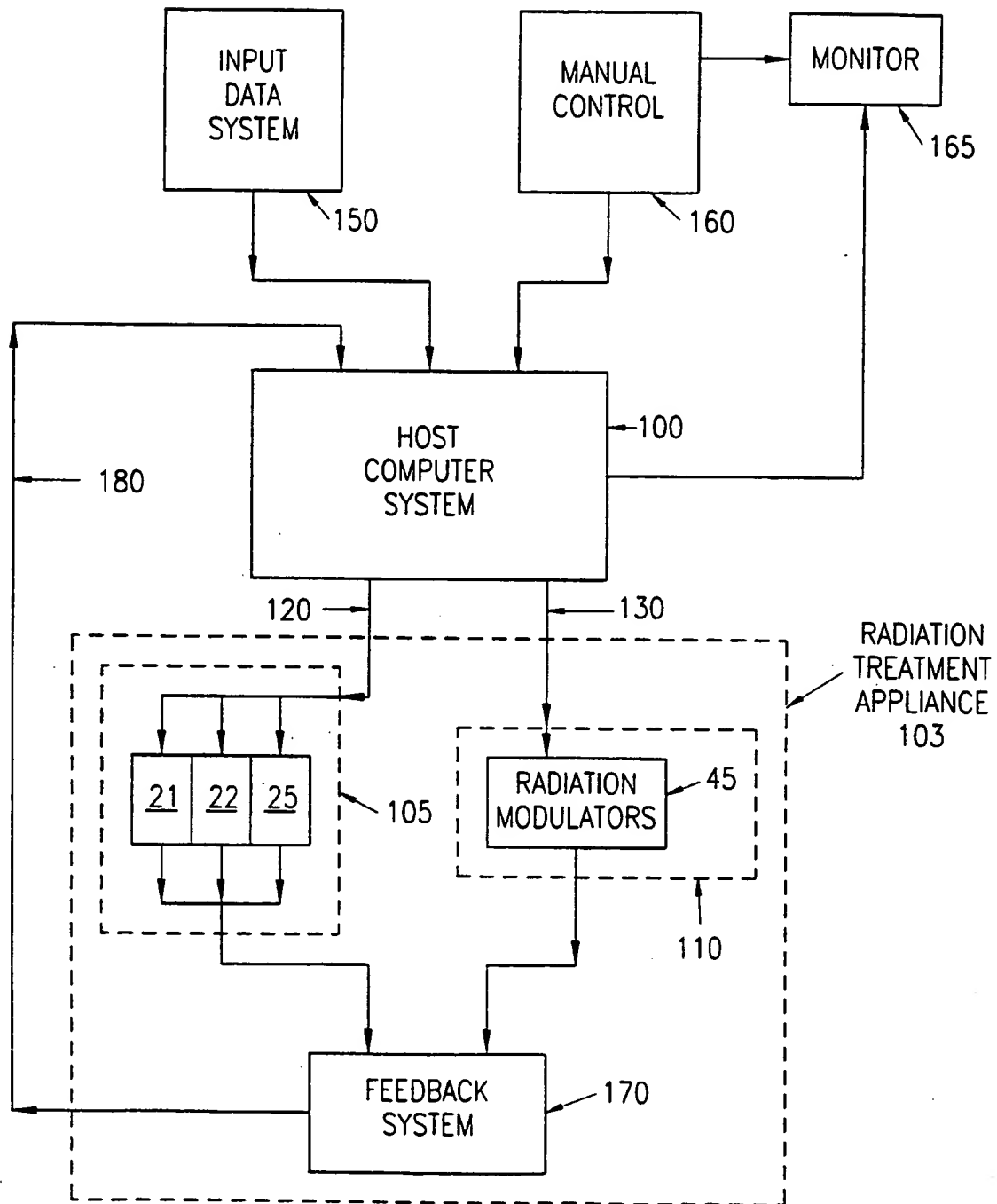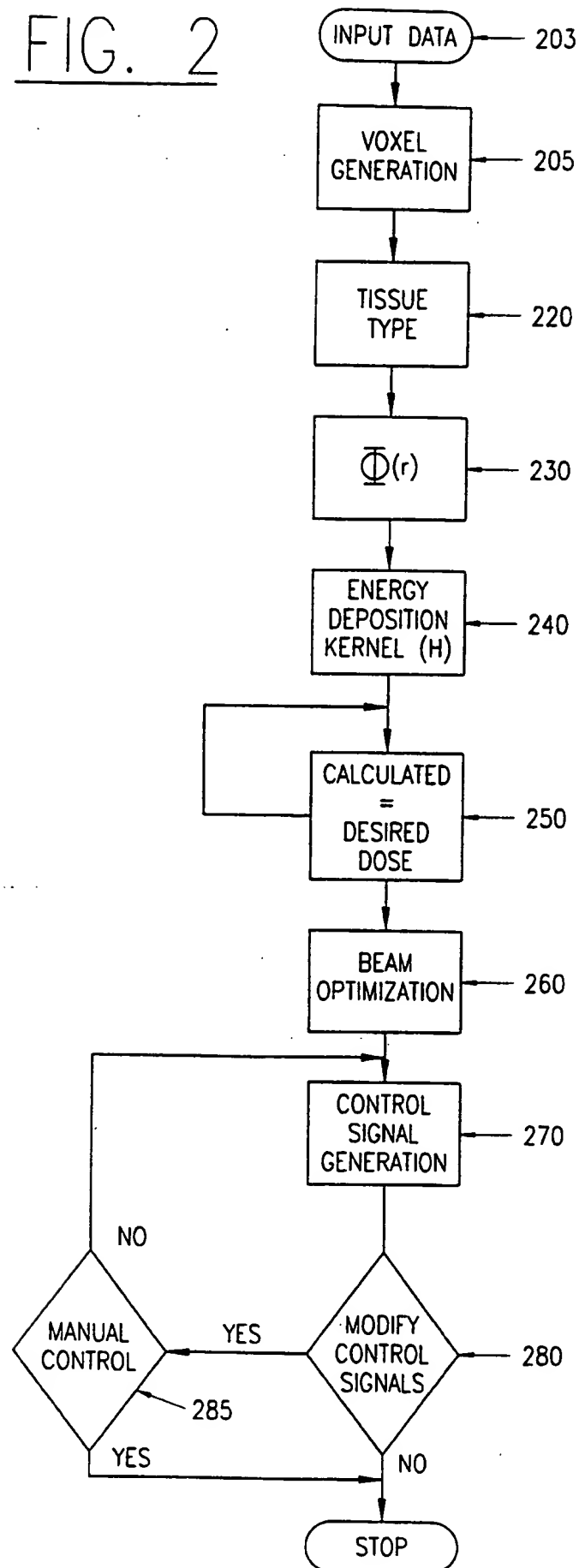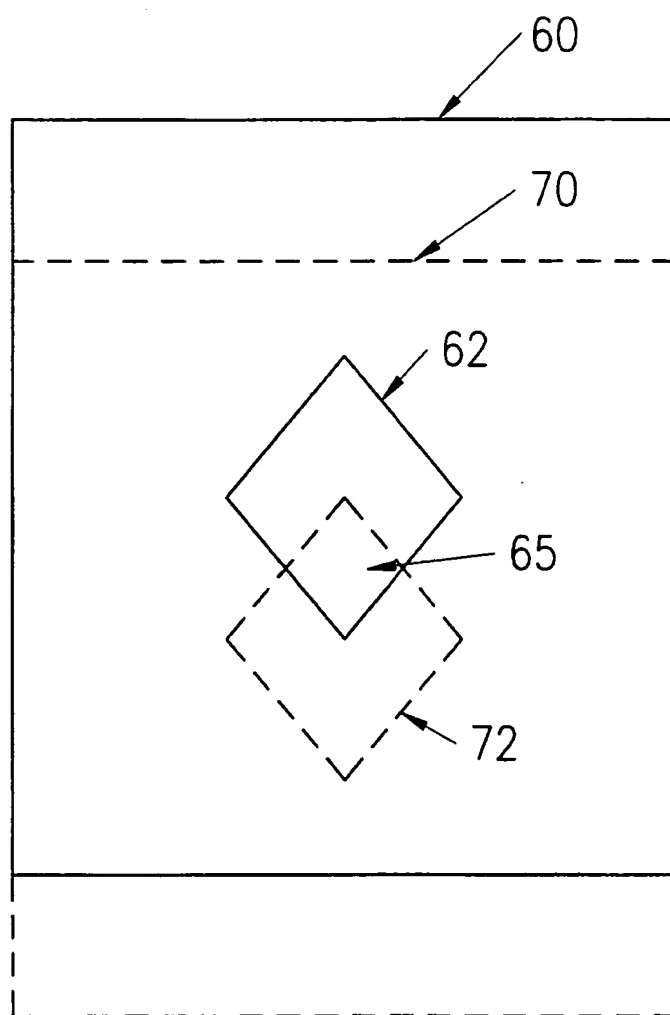35

FIG. 1   1/6

FIG. 2

```
                    ( INPUT DATA )——— 203

                    ┌─────────────┐
                    │    VOXEL    │——— 205
                    │ GENERATION  │
                    └─────────────┘

                    ┌─────────────┐
                    │   TISSUE    │——— 220
                    │    TYPE     │
                    └─────────────┘

                    ┌─────────────┐
                    │    Φ̄(r)     │——— 230
                    └─────────────┘

                    ┌─────────────┐
                    │   ENERGY    │
                    │ DEPOSITION  │——— 240
                    │ KERNEL (H)  │
                    └─────────────┘
           ┌────────────┐
           │            ▼
           │     ┌─────────────┐
           │     │ CALCULATED  │
           └─────│     =       │——— 250
                 │  DESIRED    │
                 │    DOSE     │
                 └─────────────┘

                    ┌─────────────┐
                    │    BEAM     │——— 260
                    │OPTIMIZATION │
                    └─────────────┘
      ┌─────────────────────┐
      │              ▼
      │        ┌─────────────┐
      │        │   CONTROL   │
      │        │   SIGNAL    │——— 270
      │        │ GENERATION  │
      │        └─────────────┘
      │              │
   NO │              ▼
      │         ╱─────────╲
   ╱──┴──╲ YES ╱  MODIFY   ╲
  ╱ MANUAL ╲◄──╱ CONTROL    ╲——— 280
  ╲CONTROL ╱   ╲  SIGNALS   ╱
   ╲──┬──╱  285 ╲─────────╱
  YES │              │ NO
      ▼              ▼
    ( STOP )
```

FIG. 3

FIG. 4

82   80

82 (a)   80 (a)

82 (b)   80 (b)

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FIG. 5

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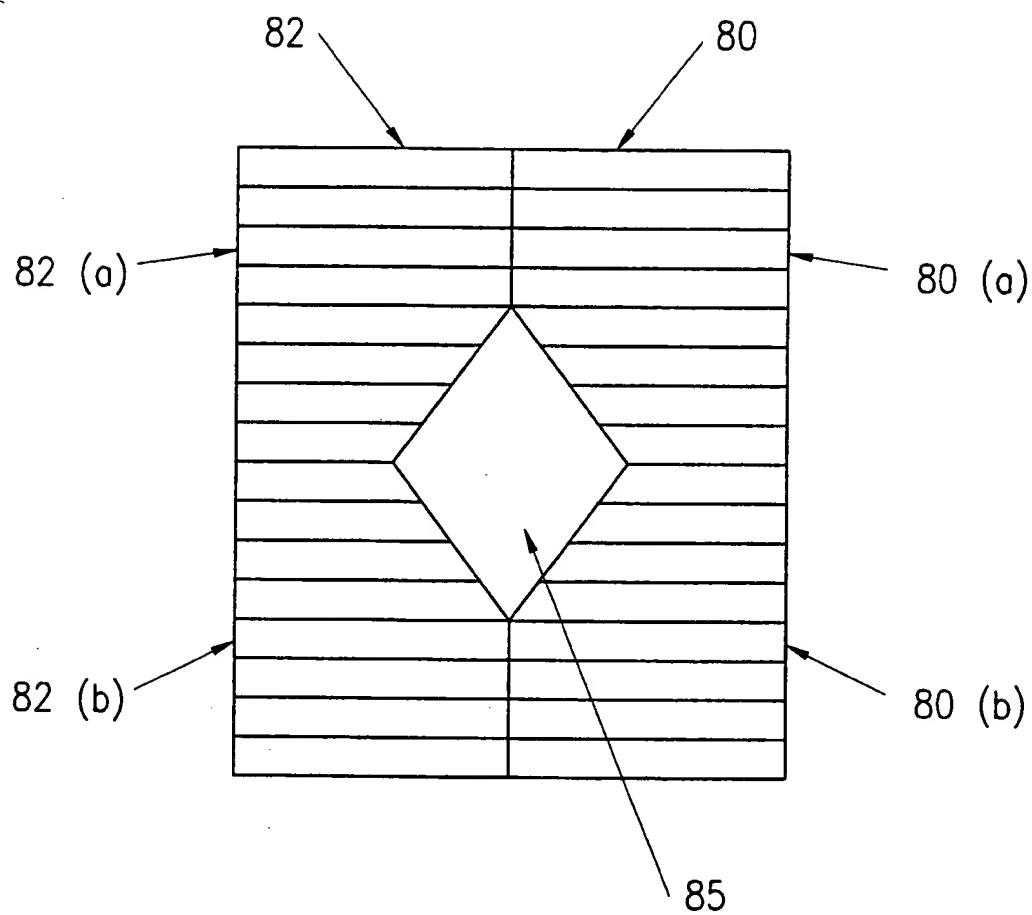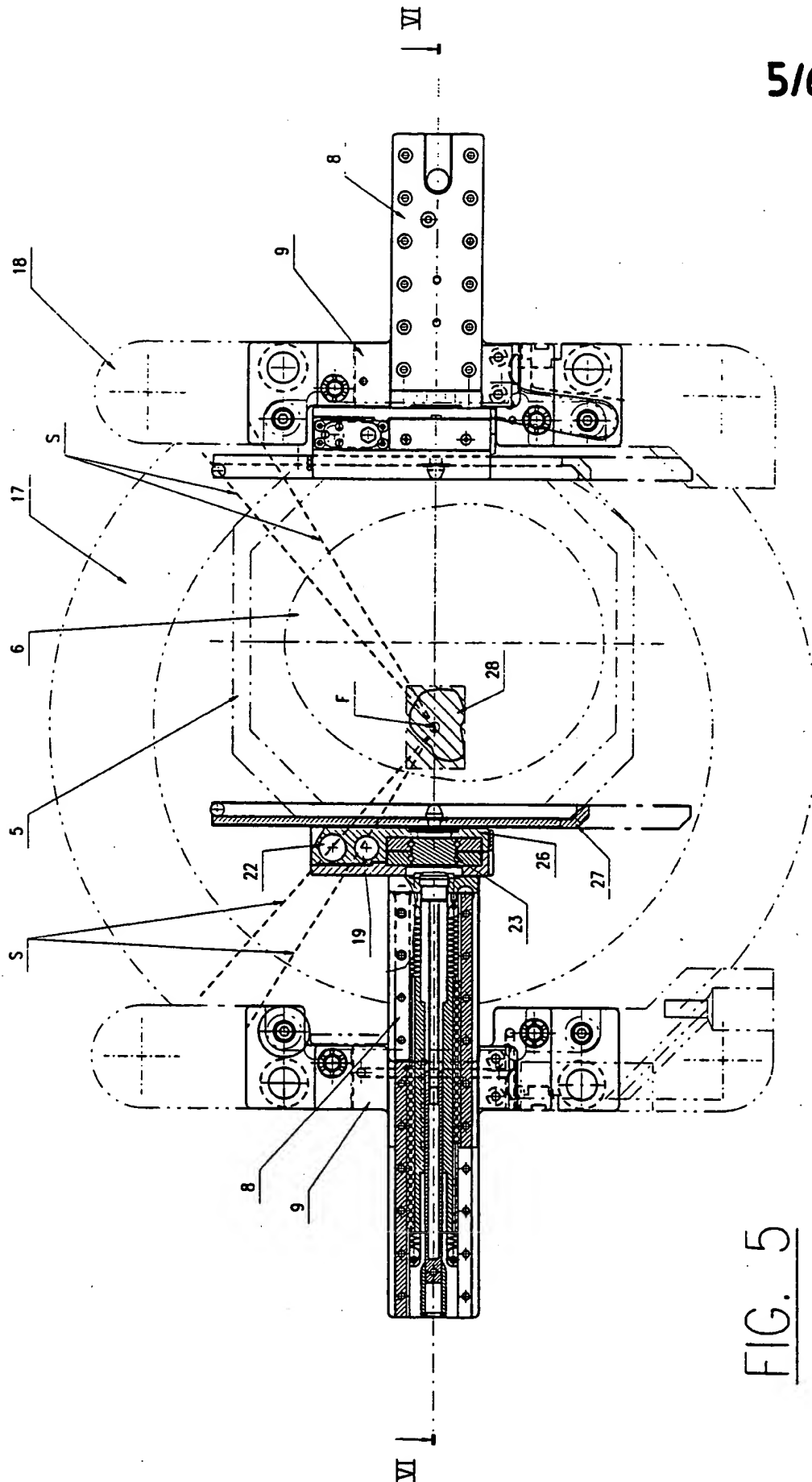
FIG. 6
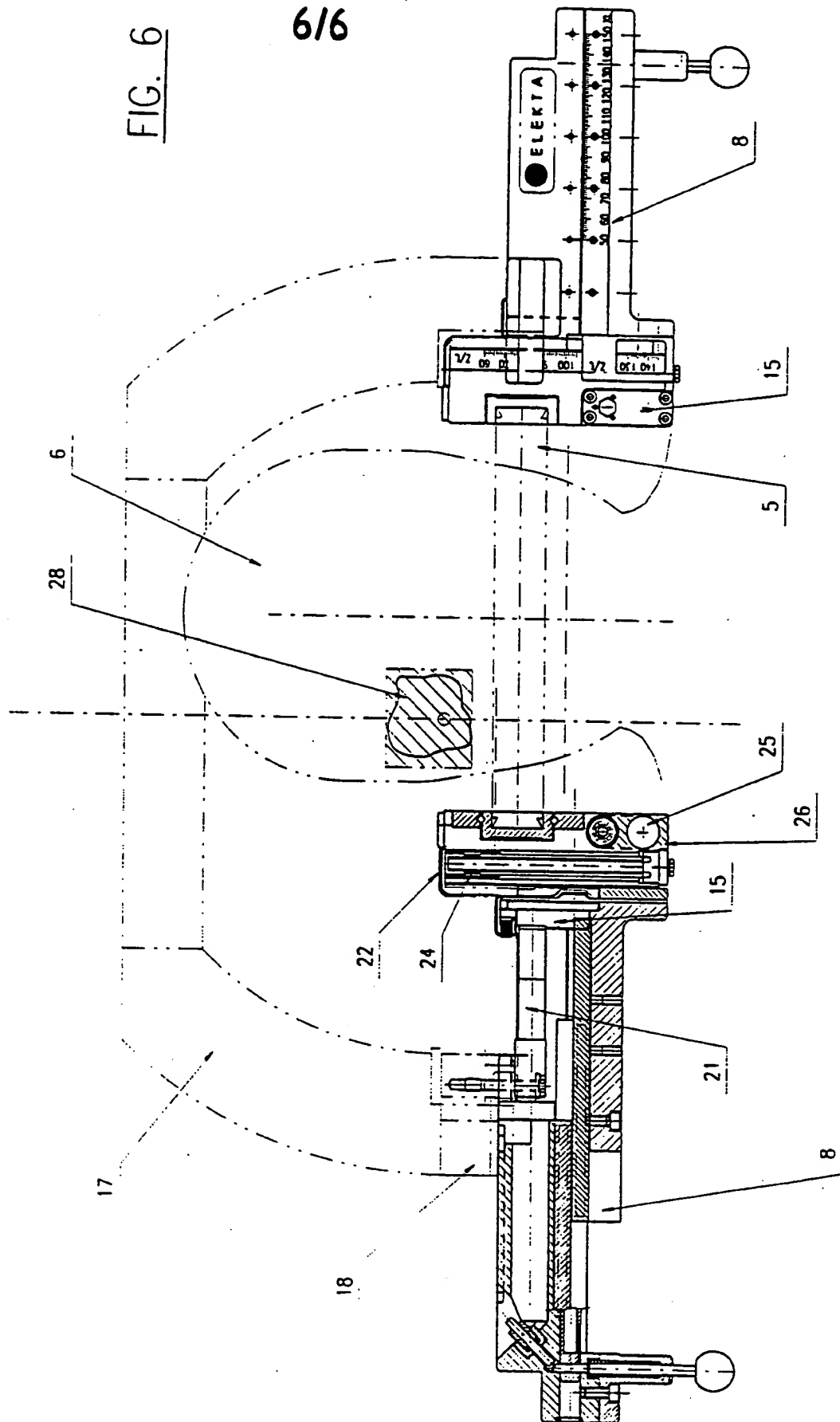
INTERNATIONAL SEARCH REPORT

	Inter.. ..onal application No. PCT/SE 95/00695

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: A61N 5/10, A61B 6/08
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: A61B, A61N, G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0562585 A2 (IKEBE, JUN), 29 Sept 1993 (29.09.93), column 2, line 23 - line 47	1,2,5,8-10
Y		6,7
	--	
X	US 5107839 A (P.V. HOUDEK ET AL.), 28 April 1992 (28.04.92), column 2, line 61 - column 3, line 20; column 9, line 2 - line 21; column 9, line 39 - line 59	1,3,4,9-12
Y		6,7,13
	--	
X	EP 0480035 A1 (YOKOGAWA MEDICAL SYSTEMS, LTD), 15 April 1992 (15.04.92), column 2, line 39 - line 56; column 4, line 16 - line 21	1,3,4,9-12
	--	

| [X] | Further documents are listed in the continuation of Box C. | [X] | See patent family annex. |

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 Sept 1995	2 7 -09- 1995

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 95/00695

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 5278886 A (T. KOBIKI ET AL.), 11 January 1994 (11.01.94), abstract --	13
P,X	US 5341292 A (R.G. ZAMENHOF), 23 August 1994 (23.08.94), abstract -- --------	1,6,7

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		US-A-	5206893	27/04/93
		WO-A-	9100057	10/01/91
US-A- 5205289	27/04/93	US-A-	5339812	23/08/94
		WO-A-	9118552	12/12/91
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		CA-A-	1333728	27/12/94
		US-A-	5099846	31/03/92
		US-A-	5143076	01/09/92
		US-A-	5176689	05/01/93
		US-A-	5354314	11/10/94
		US-A-	5398684	21/03/95
		CA-A,A-	2079094	29/09/91
		WO-A-	9114397	03/10/91
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US-A- 5341292	23/08/94	NONE		